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Uemura

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[54] WINDOW-PASSAGE DETECTION SYSTEM OF AN AIRPLANE

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[73] Assignee: **NEC Corporation**, Tokyo, Japan

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**^{6} **G08G 5/00**

[52] **U.S. Cl.** **340/947**; 340/952; 342/33; 342/35; 342/357; 701/17

[58] **Field of Search** 340/947, 952, 340/956; 342/33, 34, 35, 357, 437, 450, 413; 701/16, 17, 18, 300; 244/186, 194

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,390,949	6/1983	Beningfield et al.	244/186
4,894,655	1/1990	Joguet et al.	340/945
5,153,587	10/1992	Redlich	340/947
5,361,212	11/1994	Class et al.	340/947
5,546,095	8/1996	Lopez	343/703
5,786,773	7/1998	Murphy	340/947

FOREIGN PATENT DOCUMENTS

3-46581	2/1991	Japan .

OTHER PUBLICATIONS

An Experiment of Approach and Landing According to DGPS; proceedings of 28th symposium of *Electronic Navigation Research Institute, Ministry of Transport* (1996); pp. 13–16—No Translation.

Primary Examiner—Brent Swarthout
Attorney, Agent, or Firm—Ostrolenk, Faber, Gerb & Soffen, LLP

[57] **ABSTRACT**

A window-passage detection system has a ground system comprising: a first course generator (**3**) for generating a horizontal DDM (Differential Depth of Modulation) pattern for defining a horizontal width (**25**) of a virtual window frame by emitting a first carrier signal and a first side-band signal from a pair of first transmission antennae (**6***a* and **6***b*), a second course generator (**4**) for generating a vertical DDM pattern for defining a vertical width (**26**) of the virtual window frame by emitting a second carrier signal and a second side-band signal from a pair of second transmission antennae (**7***a* and **7***b*), and a third course generator (**5**) for generating a longitudinal DDM pattern for defining a longitudinal position (**27**) of the virtual window frame by emitting a third carrier signal and a third side-band signal from a pair of third transmission antenna (**8***a* and **8***b*). Pairs of the first to the third transmission antennae (**6***a* to **8***b*) generate three orthogonal polarization planes. With each pair of antenna, each carrier signal is emitted with the same phase and each side-band signal is emitted with inverted phase. Each carrier signal is amplitude-modulated with addition of a first and a second modulation signal, and each side-band signal is balanced-modulated with differential of the first and the second modulation signal.

6 Claims, 6 Drawing Sheets

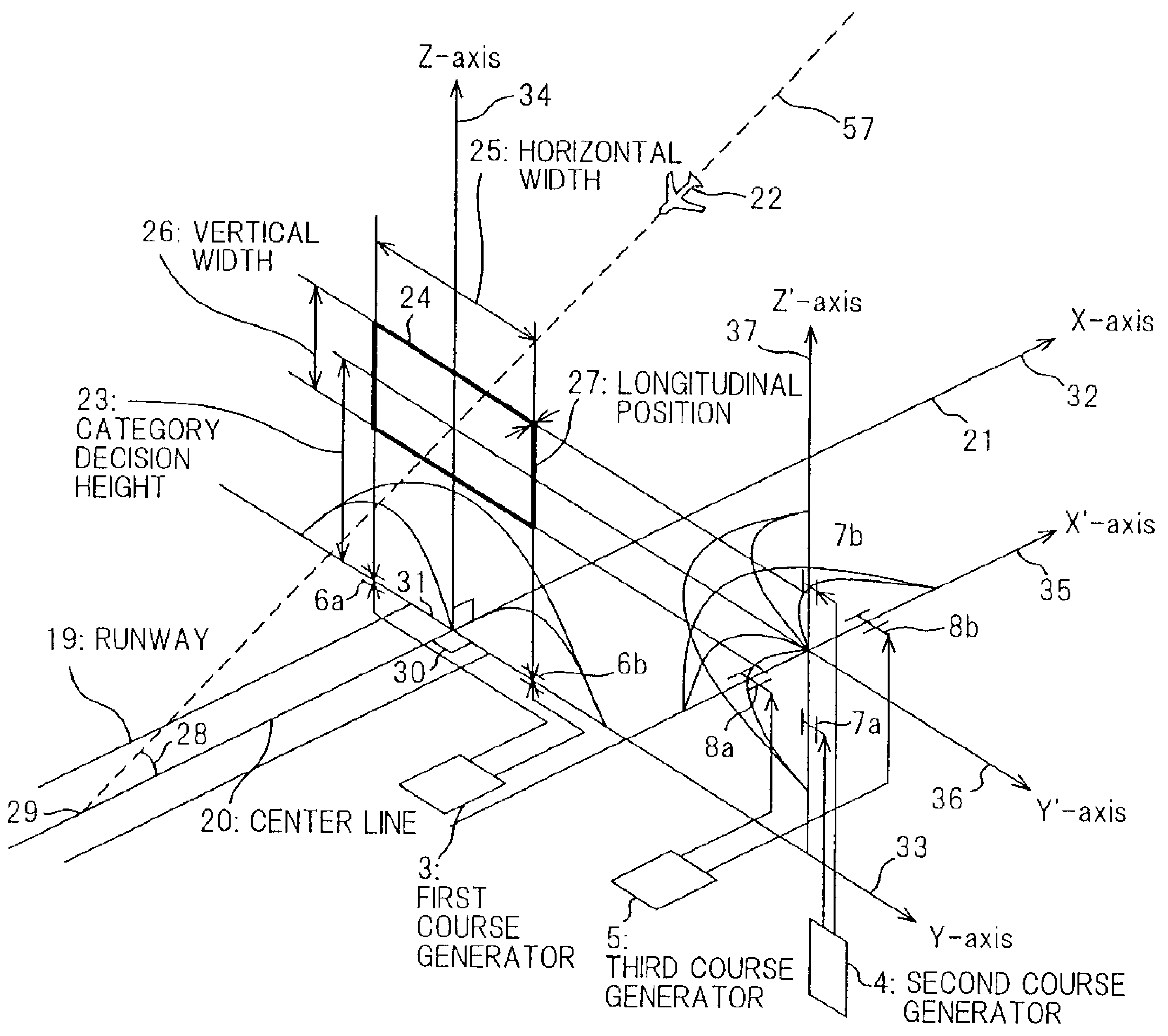


FIG. 1A

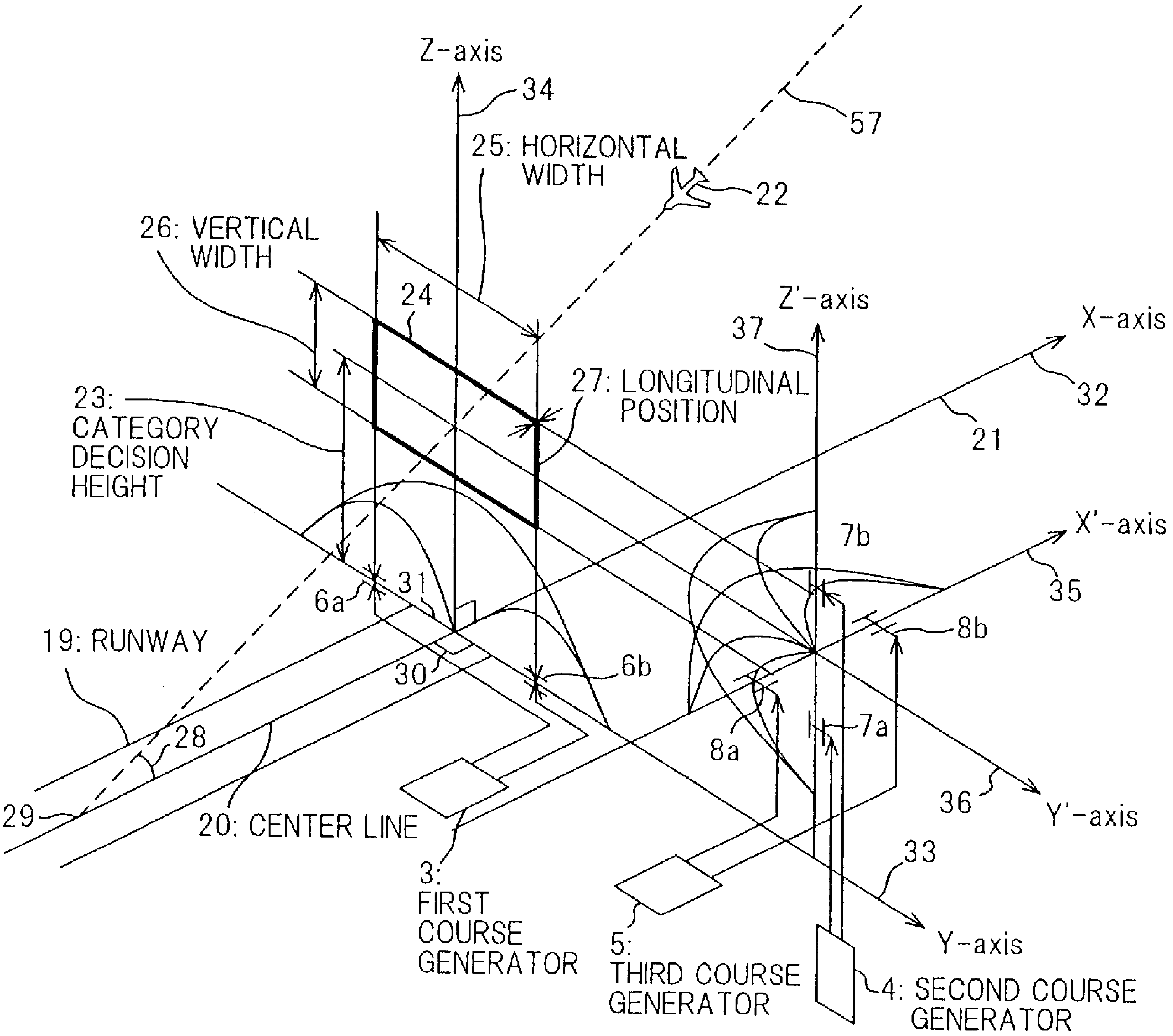

Z-axis
34
57
25: HORIZONTAL WIDTH
22
26: VERTICAL WIDTH
24
Z'-axis
37
X-axis
27: LONGITUDINAL POSITION
32
23: CATEGORY DECISION HEIGHT
21
7b
X'-axis
31
6a
35
19: RUNWAY
30
6b
8b
28
8a
7a
29
20: CENTER LINE
36
Y'-axis
33
3: FIRST COURSE GENERATOR
5: THIRD COURSE GENERATOR
Y-axis
4: SECOND COURSE GENERATOR

FIG. 1B

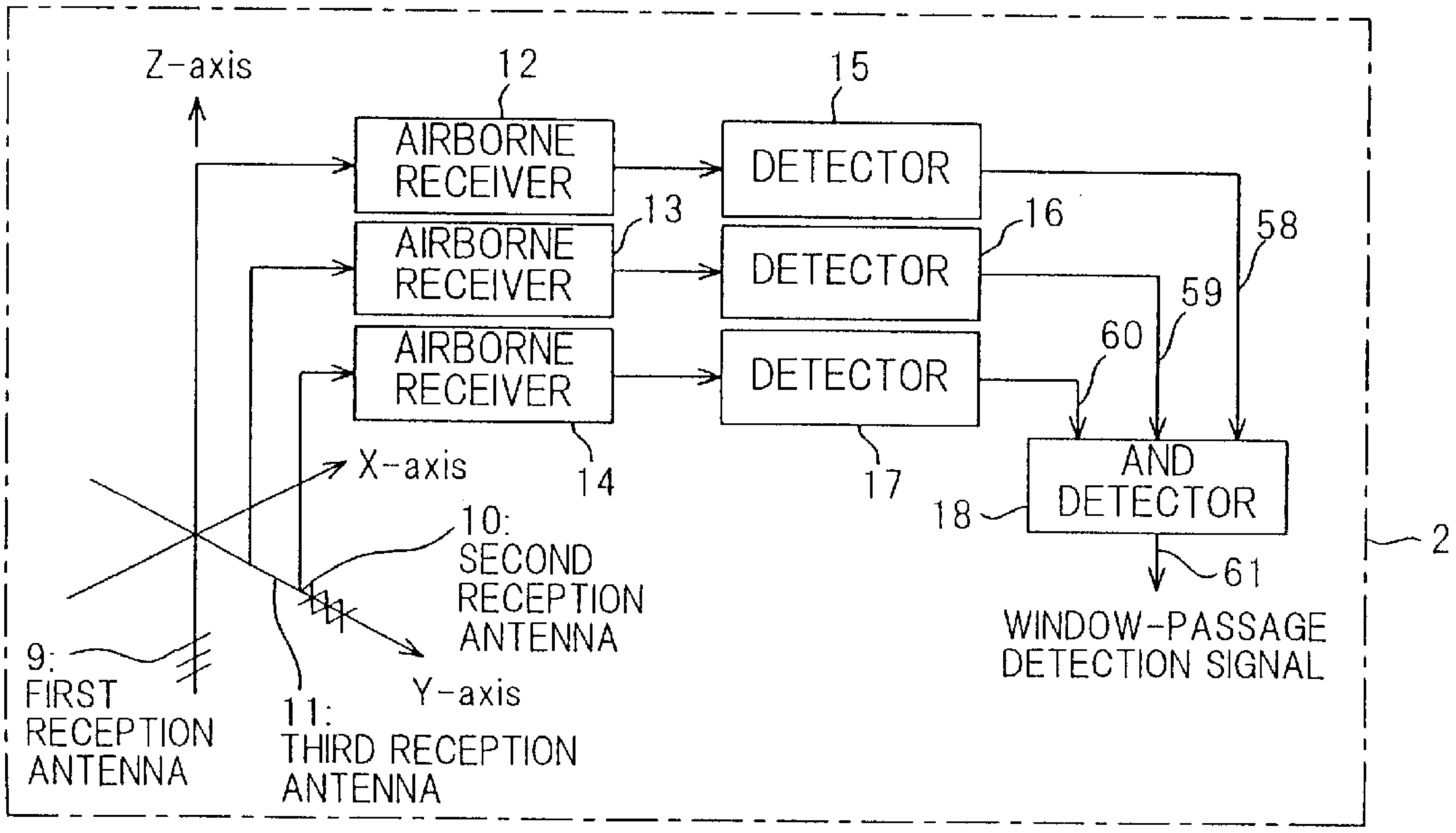

Z-axis
12
AIRBORNE RECEIVER
15
DETECTOR
13
AIRBORNE RECEIVER
16
DETECTOR
58
59
AIRBORNE RECEIVER
DETECTOR
60
X-axis
14
17
AND DETECTOR
18
2
10: SECOND RECEPTION ANTENNA
61
WINDOW-PASSAGE DETECTION SIGNAL
9: FIRST RECEPTION ANTENNA
Y-axis
11: THIRD RECEPTION ANTENNA

FIG. 2

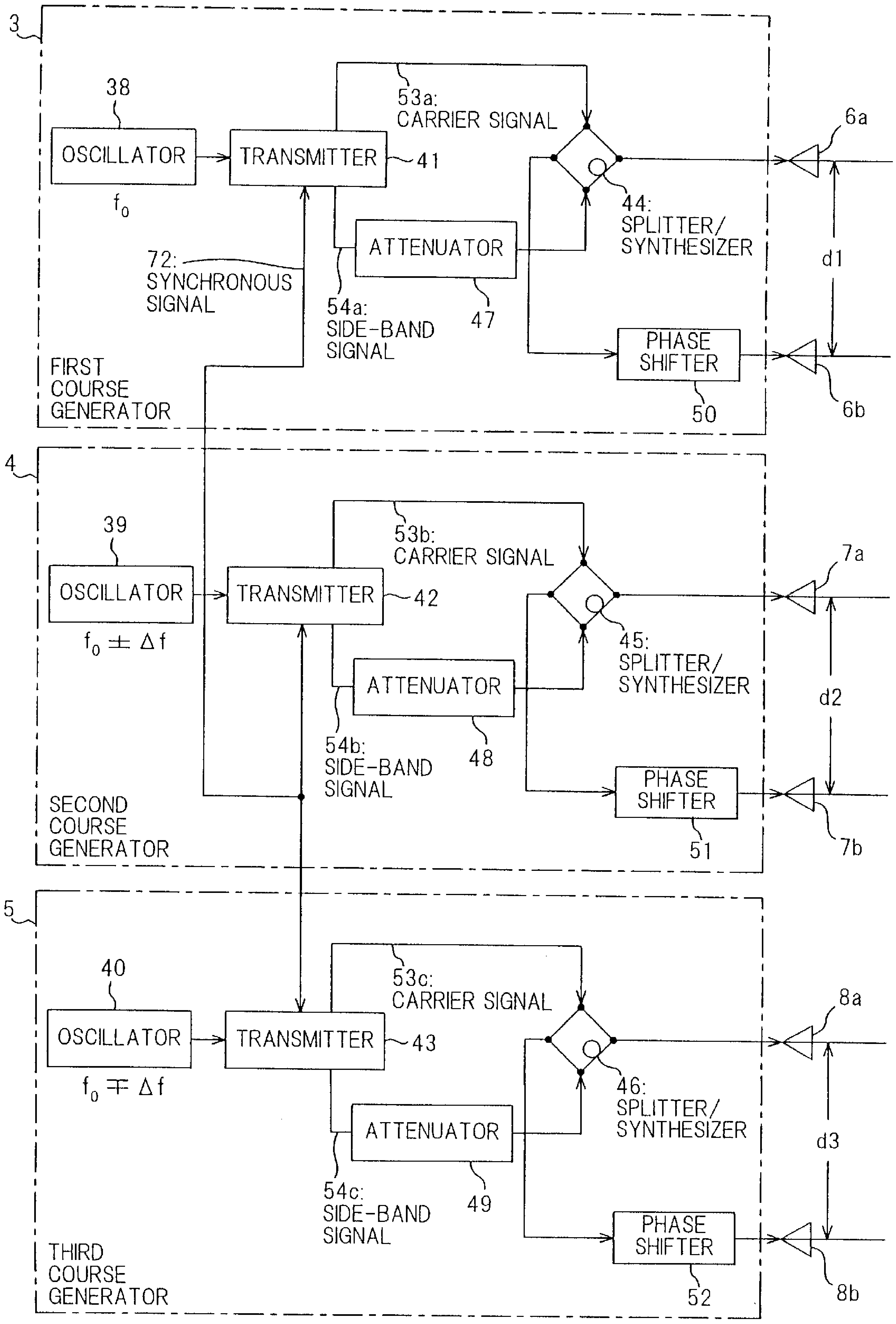

3
38
OSCILLATOR
f_0
TRANSMITTER
41
53a: CARRIER SIGNAL
44: SPLITTER/ SYNTHESIZER
6a
d1
ATTENUATOR
47
72: SYNCHRONOUS SIGNAL
54a: SIDE-BAND SIGNAL
PHASE SHIFTER
50
6b
FIRST COURSE GENERATOR
4
39
OSCILLATOR
$f_0 \pm \Delta f$
TRANSMITTER
42
53b: CARRIER SIGNAL
45: SPLITTER/ SYNTHESIZER
7a
d2
ATTENUATOR
48
54b: SIDE-BAND SIGNAL
PHASE SHIFTER
51
7b
SECOND COURSE GENERATOR
5
40
OSCILLATOR
$f_0 \mp \Delta f$
TRANSMITTER
43
53c: CARRIER SIGNAL
46: SPLITTER/ SYNTHESIZER
8a
d3
ATTENUATOR
49
54c: SIDE-BAND SIGNAL
PHASE SHIFTER
52
8b
THIRD COURSE GENERATOR

FIG. 3A

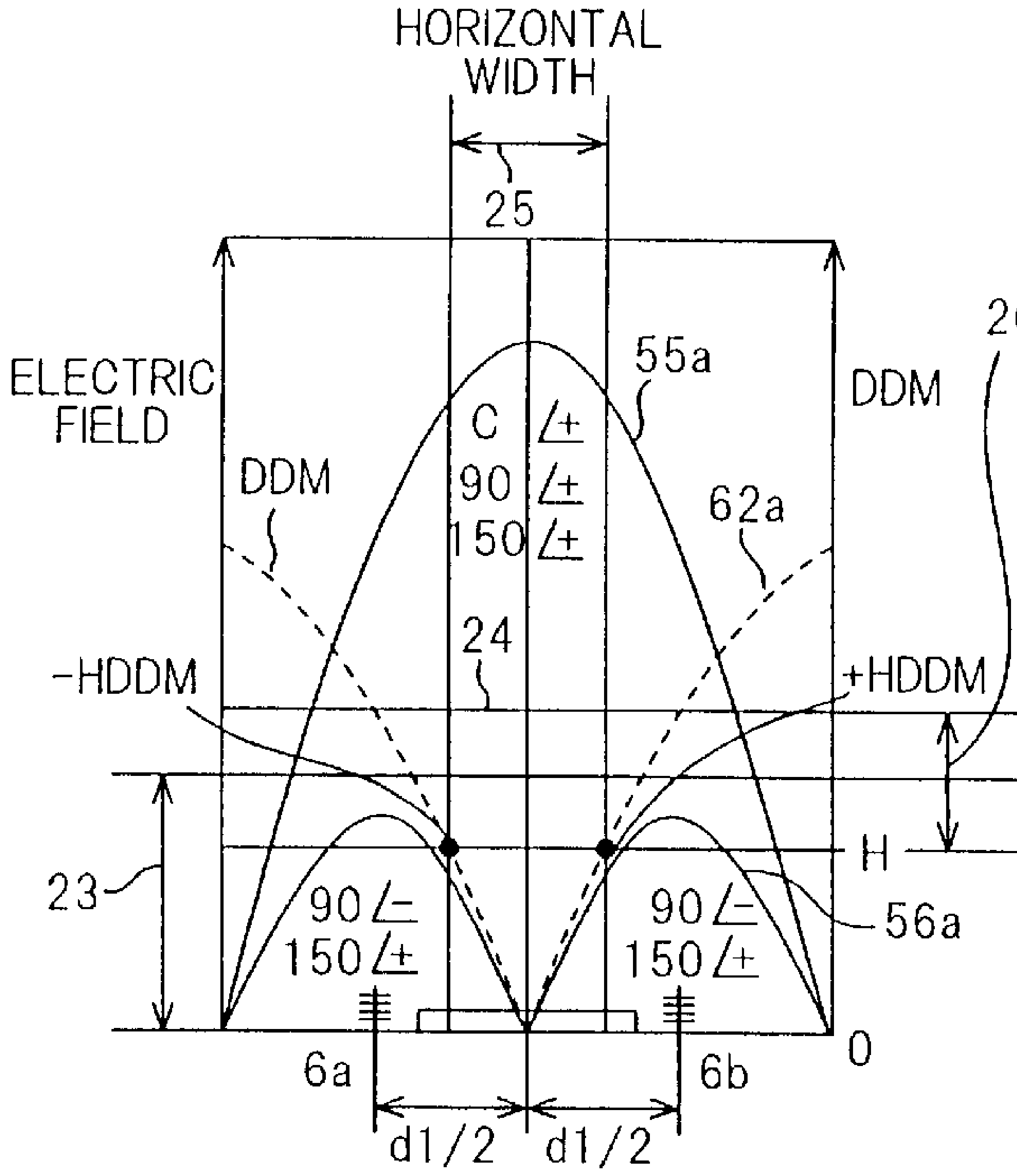


FIG. 3B

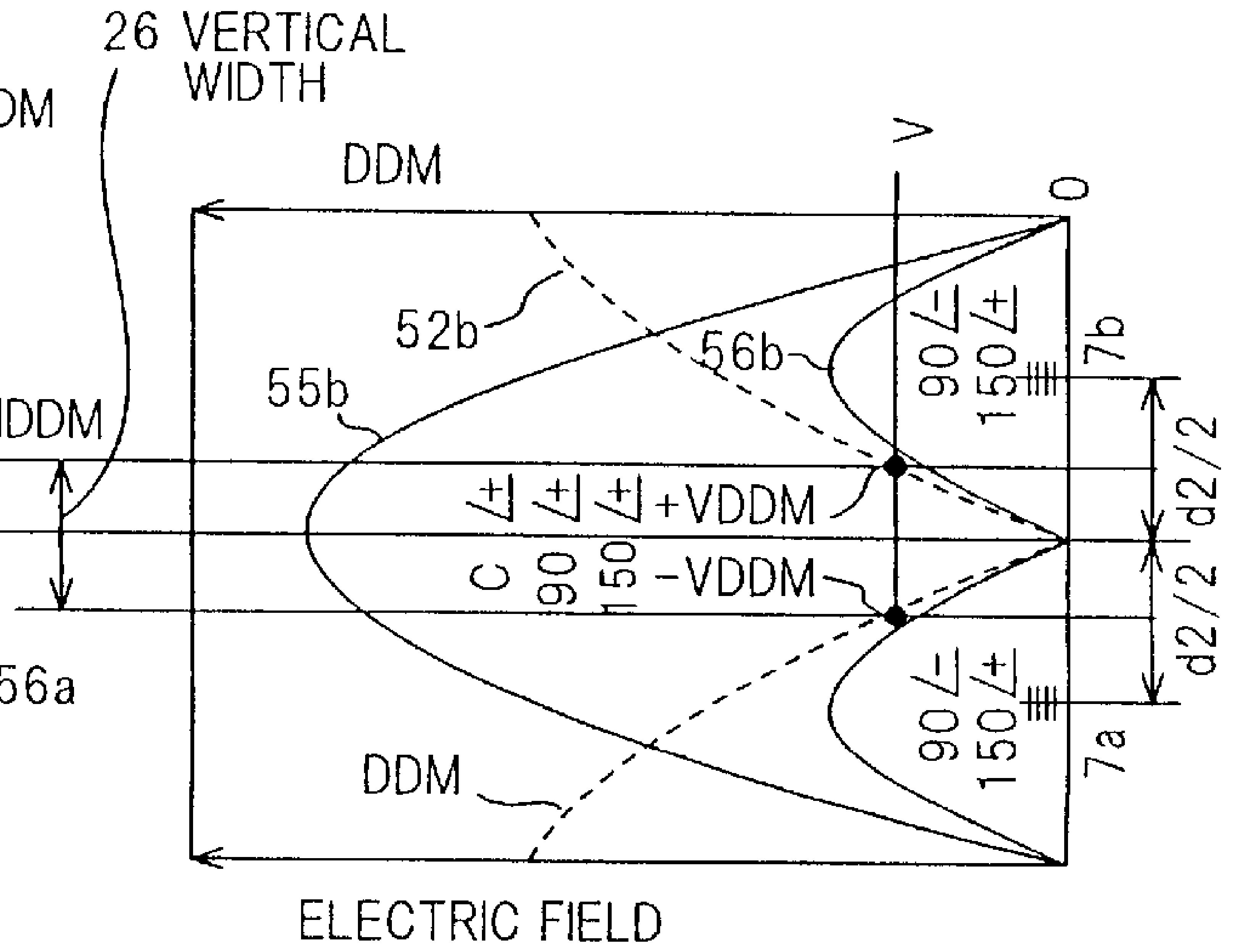


FIG. 3C

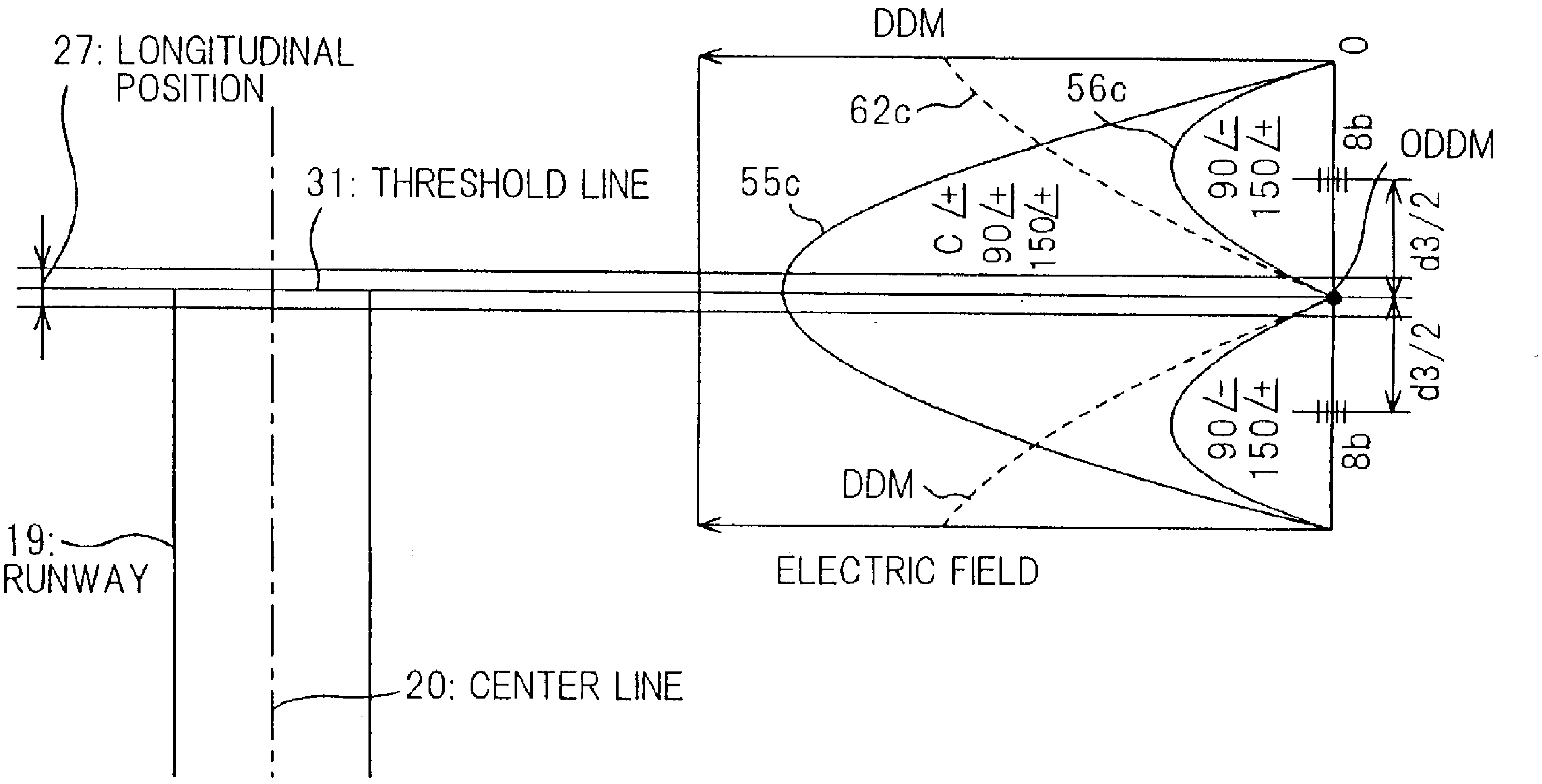


FIG. 4

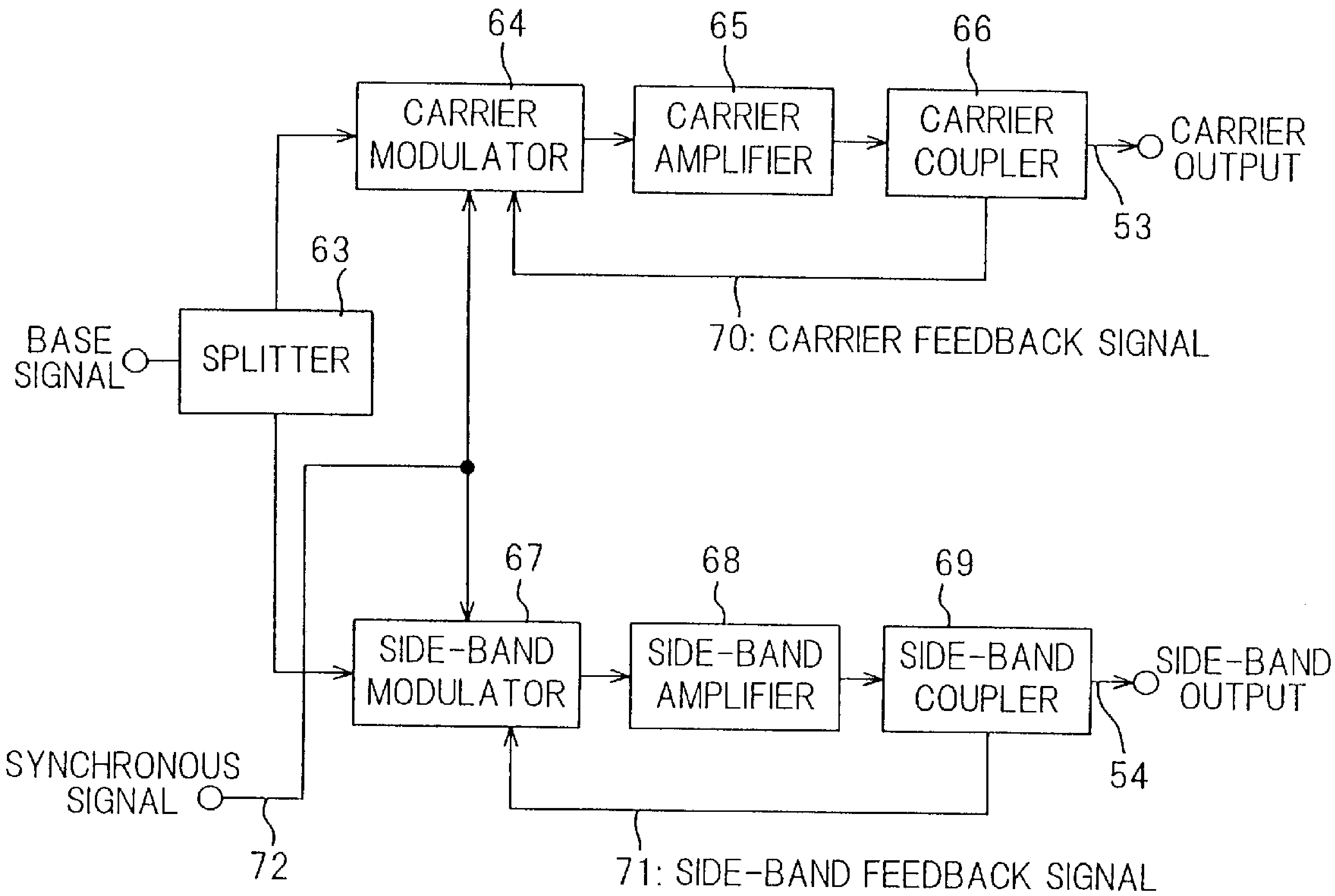

64
CARRIER MODULATOR
65
CARRIER AMPLIFIER
66
CARRIER COUPLER
CARRIER OUTPUT
53
63
BASE SIGNAL
SPLITTER
70: CARRIER FEEDBACK SIGNAL
67
SIDE-BAND MODULATOR
68
SIDE-BAND AMPLIFIER
69
SIDE-BAND COUPLER
SIDE-BAND OUTPUT
54
SYNCHRONOUS SIGNAL
72
71: SIDE-BAND FEEDBACK SIGNAL

FIG. 5

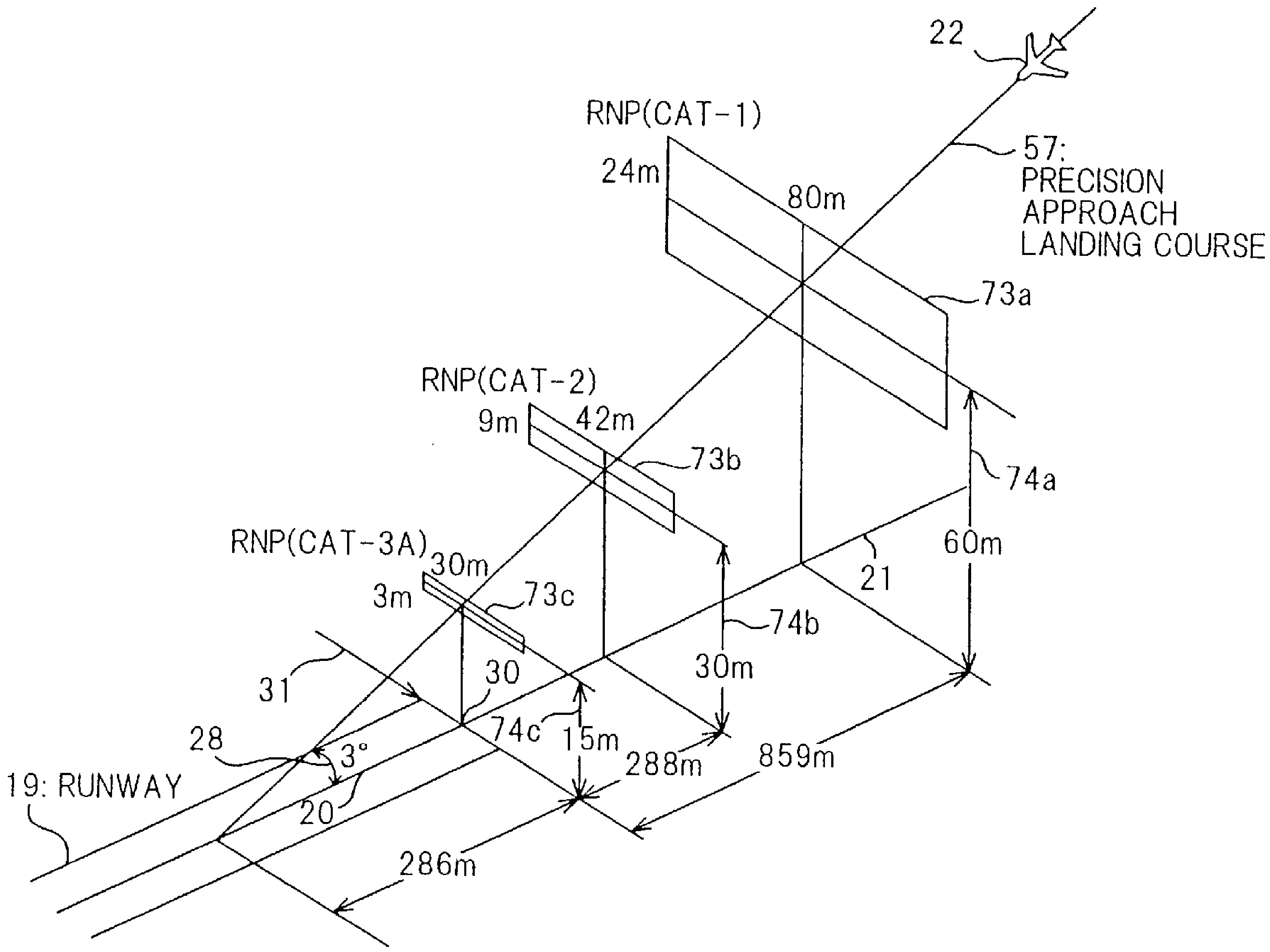
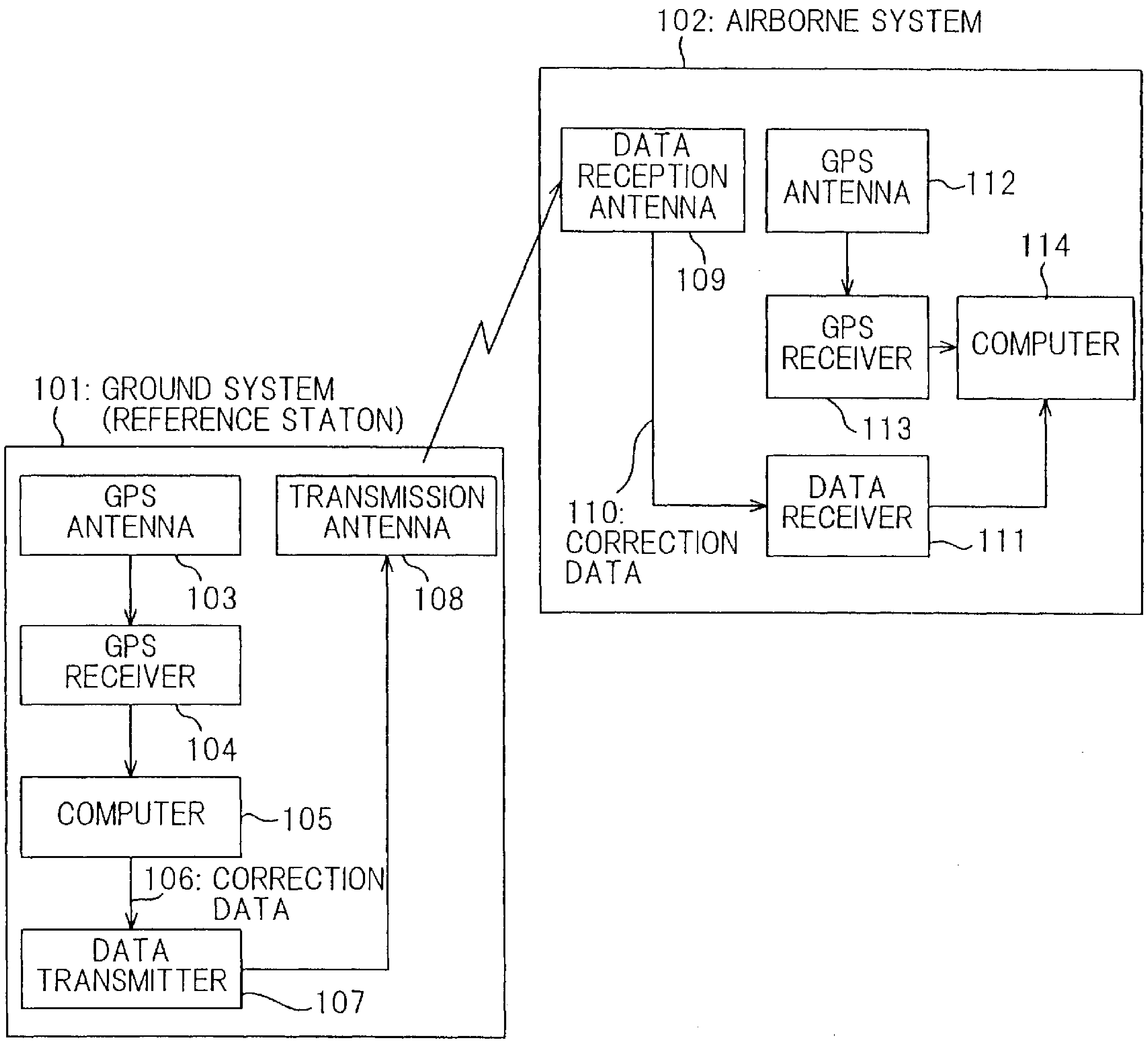

22
RNP(CAT-1)
24m
80m
57:
PRECISION
APPROACH
LANDING COURSE
73a
RNP(CAT-2)
9m
42m
73b
74a
60m
RNP(CAT-3A)
30m
3m
73c
21
74b
30m
31
30
28
3°
74c
15m
288m
859m
19: RUNWAY
20
286m

FIG. 6 PRIOR ART



WINDOW-PASSAGE DETECTION SYSTEM OF AN AIRPLANE

BACKGROUND OF THE INVENTION

The present invention relates to a window-passage detection system of an airplane for detecting a timing when the airplane passes through a window frame, that is, an appointed space including a category decision height where a final landing decision should be taken when the airplane is to be landing according to precision approach making use of a satellite navigation system, at airborne side and instantaneously at the timing.

Since 1993, the application of GPS (Global Positioning System) to the precision approach landing of the airplane has been studied at AWOP (All Weather Operating Panel) of the ICAO (International Civil Aviation Organization), and RNP (Required Navigation Performance) is proposed there for defining necessary performance for the precision approach landing.

Referring to FIG. **6**, a precision approach landing system making use of DGPS (Differential Global Positioning System) is described, which is considered to give a highest measurement precision among actually available satellite navigation systems.

The DGPS is a technique to improve measurement precision by revising three-dimensional information obtained at a mobile station making use of the pseudo-distance error measured at and transmitted from a reference position whereof precise three-dimensional position is known. Therefore, the transmission of the pseudo-distance error defines the measurement precision of the system.

The DGPS system of FIG. **6** comprises a ground system (reference station) **101** and an airborne system **102**. The ground system **101** calculates the pseudo-distance and its differential of each satellite from positional information received by a GPS receiver **104** through a GPS antenna **103** with a computer **105** based on the precise three-dimensional position of the ground system **101** which is beforehand measured. Correction data **106** obtained from the pseudo-distance and its differential is transmitted from a transmission antenna **108** through a data transmitter **107**.

In the airborne system **102**, positional information calculated from satellite signals received by a GPS receiver **113** through a GPS antenna **112** and correction data **110** received from the ground system (reference station) **101** by a data receiver **111** through a data reception antenna **109** are supplied to a computer **114**. The computer **114** obtains its precise position by revising the positional information making use of the correction data **110**.

According to experimental data presented in a paper entitled "An Experiment of Approach and Landing according to DGPS", pp. 13–16, proceedings of 28-th symposium of Electronic Navigation Research Institute, Ministry of Transport, the measurement error was about ±5 m in the DGPS system wherein a narrow correlator receiver is applied to each of the GPS receivers **104** and **113**, and the correction data **106** is measured and transmitted every 5 seconds according to data format (ASCII) of the GPS receiver **104** from the data transmitter **107** to the data receiver **111** by way of spread spectrum modulation.

On the other hand, the allowable height deviation is ±4.5 m at 30 m height for RNP category **2**, and it is ±1.5 m at 15 m height for RNP category **3**A, according to the AWOP proposal beforehand described.

Therefore, the DGPS system above described can not give sufficient exactness of cm-order necessary for the precision approach landing of RNP category **2** or RNP category **3**A, being unable to exactly detect passage of the inner window frame including the decision height of 30 m of the RNP category **2** or that of 15 m of the RNP category **3**A, at airborne side.

It may be considered to improve precision of the DGPS system for dealing with this problem. However, the DGPS systems, which are provided at reference points whereof three-dimensional position is known for transmitting GPS correction data to the airborne users by always measuring pseudo-distance errors of the GPS signals, need considerable maintenance cost without saying of their installation cost. Therefore, further precision improvement of the DGPS systems would require enormous cost.

SUMMARY OF THE INVENTION

Therefore, a primary object of the present invention is to provide a window-passage detection system of an airplane which enables to detect passage of the inner window frame defined in the space including the category decision height appointed in the RNP proposed by AWOP of ICAO, instantaneously at airborne side with precision of cm-order, in cooperation with a future satellite navigation system, such as the DGPS system, which will be the major system when adopted for the precision approach landing.

In order to achieve the object, a ground system of the window-passage detection system according to the invention comprises:

a first course generator for generating a horizontal DDM (Differential Depth of Modulation) pattern for defining a horizontal width of a virtual window frame through which a precision approach landing course of an airplane is set, by emitting a first carrier signal and a first side-band signal at the same time upwards toward the virtual window frame from a pair of first transmission antennae provided under the virtual window frame and arranged horizontally and line-symmetrically to a center line of a runway to generate a polarization plane parallel to a horizontal direction of the virtual window frame;

a second course generator for generating a vertical DDM pattern for defining a vertical width of the virtual window frame, by emitting a second carrier signal and a second side-band signal at the same time in the horizontal direction toward the virtual window frame from a pair of second transmission antennae provided sideways of the virtual window frame and arranged vertically and line-symmetrically to a horizontal line orthogonal to the center line an crossing with the precision approach landing course to generate a polarization plane parallel to a vertical direction of the virtual window frame; and

a third course generator for generating a longitudinal DDM pattern for defining a longitudinal position of the virtual window frame, by emitting a third carrier signal and a third side-band signal at the same time in the horizontal direction toward the virtual window frame from a pair of third transmission antennae provided sideways of the virtual window frame and arranged horizontally and line-symmetrically to the horizontal line orthogonal to the center line and crossing with the precision approach landing course to generate a polarization plane parallel to a normal direction of the virtual window frame.

Each of the first to the third carrier signal is obtained by amplitude-modulating each of a first to a third base signal having frequencies a little shifted from each other with the first and the second modulation signal, and each of the first to the third side-band signal is obtained by balanced-modulating corresponding each of the first to the third base signal with the first modulation signal whereof a phase is inverted and the second modulation signal.

One of each pair of the first to the third transmission antennae is supplied with corresponding each of the first to the third side-band signal and corresponding each of the first to the third carrier signal signal, and the other of each pair of the first to the third transmission antennae is supplied with corresponding each of the first to the third side-band signal whereof a phase is inverted and corresponding each of the first to the third carrier signal.

An airborne system of the window-passage detection system according to the invention, which is provided on an airplane, comprises:

a first detector for detecting passage of the airplane inside of the horizontal width of the virtual window frame, from output of a first airborne receiver having a first reception antenna of the same polarization plane with the pair of the first transmission antennae;

a second detector for detecting passage of the airplane inside of the vertical width of the virtual window frame, from output of a second airborne receiver having a second reception antenna of the same polarization plane with the pair of the second transmission antennae;

a third detector for detecting passage of the airplane traversing the longitudinal position of the virtual window frame, from output of a third airborne receiver having a third reception antenna of the same polarization plane with the pair of the third transmission antennae; and

an AND detector for detecting passage of the airplane inside of the virtual window frame, from AND logic of outputs of the first to the third detector.

Therefore, the passage of the airplane through the inner window frame appointed in the RNP can be detected instantaneously at airborne side with sufficient precision.

Further, the first to the third course generator can be realized making use of the same technique as is applied to the Localizer or the Glide-Path transmitter, the splitter/synthesizer or the transmission antenna of an actual ILS (Instrument Landing System), and by applying the same technique, ILS airborne receivers actually equipped in the airplane can be used as the first to the third airborne receiver. Therefore, the window-passage detection system of the embodiment can be embodied with a minimum cost. Still further, the accuracy and the reliability of the ILS, which can detect the course deviation or the height deviation of cm-level, are already well proved through flight examinations and the evaluation tests.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing, further objects, features, and advantages of this invention will become apparent from a consideration of the following description, the appended claims, and the accompanying drawings wherein the same numerals indicate the same or the corresponding parts.

In the drawings:

FIG. **1**A is a schematic diagram illustrating the ground system **1** according to an embodiment of the invention;

FIG. **1**B is a block diagram illustrating the airborne system **2** according to the embodiment;

FIG. **2** is a block diagram illustrating a configuration of the first to the third course generator **3** to **5** of FIG. **1**A;

FIG. **3**A is a graphic chart schematically illustrating electric field patterns (**55***a* and **56***a*) and a DDM (Differential Depth of Modulation) pattern (**62***a*) generated by the first course generator **3** of FIG. **1**;

FIG. **3**B is a graphic chart schematically illustrating electric field patterns (**55***b* and **56***b*) and a DDM pattern (**62***b*) generated by the second course generator **4**;

FIG. **3**C is a graphic chart schematically illustrating electric field patterns (**55***c* and **56***c*) and a DDM pattern (**62***c*) generated by the third course generator **5**;

FIG. **4** is a block diagram illustrating the first to the third transmitter **41** to **43** of FIG. **1** having the same configuration;

FIG. **5** is a schematic diagram illustrating another embodiment of the invention; and

FIG. **6** is a block diagram illustrating a conventional precision approach landing system making use of DGPS.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now, embodiments of the present invention will be described in connection with the drawings.

A window-passage detection system of the invention has a ground system **1** and an airborne system **2**.

FIG. **1**A is a schematic diagram illustrating the ground system **1** according to an embodiment of the invention, comprising:

a first course generator **3** for defining a horizontal width **25** of an appointed space **24** which is to be provided parallel to a first vertical plane perpendicular to a center line **20** of a runway **19** at an end of the runway **19**, so that the center of the horizontal width **25** is positioned on a second vertical plane including the center line **20**;

a second course generator **4** for defining a vertical width **26** of the appointed space **24**, so that the center of the vertical width **26** is positioned on a horizontal plane including a category decision height **23**;

a third course generator **5** for defining a longitudinal position **27** of the appointed space **24**, so that the longitudinal position **27** coincide with the first vertical plane;

at least one pair of first transmission antennae **6***a* and **6***b* connected to the first course generator **3** and arranged on the first vertical plane symmetrically to the second vertical plane;

at least one pair of second transmission antennae **7***a* and **7***b* connected to the second course generator **4** and arranged on the first vertical plane symmetrically to the horizontal plane including the category decision height **23**; and

at least one pair of third transmission antennae **8***a* and **8***b* connected to the third course generator **5** and arranged on the horizontal plane including the category decision height **23** symmetrically to the first vertical plane.

FIG. **1**B is a block diagram illustrating the airborne system **2** according to the embodiment, comprising a first reception antenna **9** having the same polarization plane with the first transmission antennae **6***a* and **6***b,* a second reception antenna **10** having the same polarization plane with the second transmission antennae **7***a* and **7***b,* a third reception antenna **11** having the same polarization plane with the third transmission antennae **8***a* and **8***b,* a first to a third airborne receiver **12** to **14** each connected to each of the first to the third reception antenna **9** to **11**, respectively, a first to a third detector **15** to **17** each connected to each of the first to the third airborne receiver **12** to **14**, respectively, and an AND detector **18**.

FIG. **2** is a block diagram illustrating a configuration of the first to the third course generator **3** to **5**.

The first course generator **3** comprises a first oscillator **38** for oscillating a first base frequency of f_0, a first transmitter **41** for generating a first carrier signal **53***a* and a first side-band signal **54***a* by amplitude-modulating and balanced-modulating the first base frequency f_0 with a first and a second modulation signal (90 and 150 Hz having the same amplitude, for example), a first attenuator **47** for attenuating amplitude of the first side-band signal **54***a,* a first splitter/synthesizer **44** for splitting and synthesizing the first carrier signal **53***a* and the first side-band signal **54***a* after attenuated by the first attenuator **47**, and a first phase shifter **50** for adjusting phase difference between two synthesized signals output from the first splitter/synthesizer **44** each to be supplied to each of the first transmission antennae **6***a* and **6***b*.

The second course generator **4** comprises a second oscillator **39** for ocsillating a second base frequency of $f_0 \pm \Delta f$ a little shifted from the first base frequency f_0, a second transmitter **42** for generating a second carrier signal **53***b* and a second side-band signal **54***b* by amplitude-modulating and balanced-modulating the second base frequency $f_0 \pm \Delta f$ with the first and the second modulation signal, a second attenuator **48** for attenuating amplitude of the second side-band signal **54***b,* a second splitter/synthesizer **45** for splitting and synthesizing the second carrier signal **53***b* and the second side-band signal **54***b* after attenuated by the second attenuator **48**, and a second phase shifter **51** for adjusting phase difference between two synthesized signals output from the second splitter/synthesizer **45** each to be supplied to each of the second transmission antennae **7***a* and **7***b*.

Similarly, the third course generator **5** comprises a third oscillator **40** for oscillating a third base frequency of $f_0 \mp \Delta f$ a little shifted from the first base frequency f_0 to the other side than the second base frequency $f_0 \pm \Delta f$, a third transmitter **43** for generating a third carrier signal **53***c* and a third side-band signal **54***c* by amplitude-modulating and balanced-modulating the third base frequency $f_0 \mp \Delta f$ with the first and the second modulation signal, a third attenuator **49** for attenuating amplitude of the third side-band signal **54***c,* a third splitter/synthesizer **46** for splitting and synthesizing the third carrier signal **53***c* and the second side-band signal **54***c* after attenuated by the third attenuator **49**, and a third phase shifter **52** for adjusting phase difference between two synthesized signals output from the third splitter/synthesizer **46** each to be supplied to each of the third transmission antennae **8***a* and **8***b*.

FIG. **3**A is a graphic chart schematically illustrating electric field patterns (**55***a* and **56***a*) and a DDM (Differential Depth of Modulation) pattern (**62***a*) generated by the first course generator **3** of FIG. **1** on the first vertical plane. FIG. **3**B is a graphic chart schematically illustrating electric field patterns (**55***b* and **56***b*) and a DDM pattern (**62***b*) generated by the second course generator **4** on the first vertical plane, too. And FIG. **3**C is a graphic chart schematically illustrating electric field patterns (**55***c* and **56***c*) and a DDM pattern (**62***c*) generated by the second course generator **5** on the horizontal plane including the category decision height **23**.

FIG. **4** is a block diagram illustrating the first to the third transmitter **41** to **43** having the same configuration, each comprising a splitter **63** for splitting respective each of the first to the third base frequency supplied thereto into two signals, a carrier modulator **64** for generating a carrier signal by modulating one of the two signals with the first and the second modulation signal synchronized to a synchronous signal **72**, a carrier amplifier **65** for amplifying the carrier signal, a carrier coupler **66** for obtaining a carrier feedback signal **70** from the carrier signal **53** to be output as respective each of the first to the third carrier signal **53***a* to **53***c,* a side-band modulator **67** for generating a side-band signal by modulating the other of the two signals split by the splitter **63** with the first and the second modulation signal, a side-band amplifier **68** for amplifying the side-band signal, and a side-band coupler **69** for obtaining a side-band feedback signal **71** from the side-band signal **54** to be output as respective each of the first to the third side-band signal **54***a* to **54***c*.

Now, operation of the embodiment is described referring to FIGS. **1**A to **3**C.

The horizontal width **25** of the appointed space **24** including the category decision height **23** is detected by receiving the electric field **55***a* of the first carrier signal **53***a* and the electric field **56***a* of the first side-band signal **54***a* emitted at the same time from the first transmission antennae **6***a* and **6***b* by way of the first reception antenna **9** of the airborne system **2** having the same polarization plane with the first transmission antennae **6***a* and **6***b*.

The first carrier signal **53***a* generated by the first transmitter **41** is supplied to the first splitter/synthesizer **44** and splitted into two signals, whereof one is supplied directly to one (**6***a*) of the first transmission antennae and the other is supplied to the other (**6***b*) of the first transmission antennae through the first phase shifter **50**. On the other hand, the first side-band signal **54***a* generated by the first transmitter **41** is supplied to the first splitter/synthesizer **44** through the first attenuator **47** and splitted into two signals, whereof one is supplied to said one (**6***a*) of the first transmission antenna after inverted, that is, phase-shifted by 180°, and the other is supplied to the other (**6***b*) of the first transmission antennae through the first phase shifter **50**.

Therefore, the first carrier signal **53***a* is emitted with the same phase form both of the first transmission antennae **6***a* and **6***b* which are arranged symmetrically to the second vertical plane including the center line **20** of the runway **19**, generating an electric field pattern having single peak above the center line **20** as represented by the electric field pattern **55***a* of FIG. **3**A.

On the other hand, phase of the first side-band signal **54***a* emitted from each of the first transmission antennae **6***a* and **6***b* is 180° different with each other. Therefore, an electric field pattern having two peaks, as represented by the electric field pattern **56***a* of FIG. **3**A, is generated giving null field above the center line **20**. The first phase shifter **50** is provided for so adjusting the phase of the first side-band signal **54***a* to be supplied to the other (**6***b*) of the first transmission antennae that the side-band null plane coincides with the second vertical plane.

The first airborne receiver **12** detects its course by comparing modulation depths of the first and the second modulation signal obtained from the electric field **55***a* of the first carrier signal **53***a* and the electric field **56***a* of the first side-band signal **54***a*.

For example, just above an extension **21** of the center line **20**, the first airborne receiver **12** receives only the electric field **55***a* of the first carrier signal **53***a,* wherein modulation depths of the first and the second modulation signal are the same, and the first airborne receiver **12** outputs 0 DDM, indicating to be just on the course.

When the airplane **22** is positioned at right side of the center of the appointed space **24** (of FIG. **3**A), electric field of the first side-band signal **54***a* emitted from the other (**6***b*) of the first transmission antennae, and consequently, the first modulation signal (90 Hz, in the example) becomes dominant, giving a positive DDM value. At the right edge of the appointed space **24**, the DDM value shows a right allowable limit +HDDM. When the airplane **22** is positioned at left side of the center of the appointed space **24**, the second modulation signal (150 Hz, in the example) becomes dominant, giving a negative DDM value. At the left edge of the appointed space **24**, the DDM values shows a left allowable limit −HDDM.

Here, the DDM value is given as follows;

$$DDM=(M90-M150)/C,$$

M90, M150 and C being amplitude of the first modulation signal, the second modulation signal and their carrier signal (the first base frequency f_0, here), respectively. Having excellent AGC (Auto Gain Control) characteristic, the first airborne receiver **12** outputs a signal just in proportion to the DDM.

The limit value of the horizontal DDM (±HDDM), corresponding to the horizontal width **25** of the appointed space **24**, is adjusted by controlling the comparative intensity of the electric field **56***a* of the first side-band signal **54***a* by way of the first attenuator **47** of the first course generator **3**.

Detection of the vertical width **26** of the appointed space **24** is performed similarly, that is, by receiving the electric field **55***b* of the second carrier signal **53***b* and the electric field **56***b* of the second side-band signal **54***b* emitted at the same time from the second transmission antennae **7***a* and **7***b* by way of the second reception antenna **10** of the airborne system **2** having the same polarization plane with the second transmission antennae **7***a* and **7***b*.

The second carrier signal **53***b* generated by the second transmitter **42** is supplied to the second splitter/synthesizer **45** and splitted into two signals, whereof one is supplied directly to one (**7***a*) of the second transmission antennae and the other is supplied to the other (**7***b*) of the second transmission antennae through the second phase shifter **51**. On the other hand, the second side-band signal **54***b* generated by the second transmitter **42** is supplied to the second splitter/synthesizer **45** through the second attenuator **48** and splitted into two signals, whereof one is supplied to said one (**7***a*) of the second transmission antennae after inverted, that is, phase-shifted by 180°, and the other is supplied to the other (**7***b*) of the second transmission antennae through the second phase shifter **51**.

Therefore, the second carrier signal **53***b* is emitted with the same phase form both of the second transmission antennae **7***a* and **7***b* which are arranged on the first vertical plane symmetrically to the horizontal plane including the category decision height **23** at a position appropriately offset from the second vertical plane including the center line **20** of the runway **19**, and generates an electric field pattern having single peak at the category decision height **23** as represented by the electric field pattern **55***b* of FIG. 3B.

On the other hand, phase of the second side-band signal **54***b* emitted from each of the second transmission antennae **7***a* and **7***b* is 180° different with each other. Therefore, an electric field pattern having two peaks, as represented by the electric field pattern **56***b* of FIG. 3B, is generated giving null field at the category decision height **23**. The second phase shifter **51** is provided for so adjusting the phase of the second side-band signal **54***b* to be supplied to the other (**7***b*) of the second transmission antennae that the side-band null plane coincides with the horizontal plane including the category decision height **23**.

The second airborne receiver **13** detects its course by comparing modulation depths of the first and the second modulation signal obtained from the electric field **55***b* of the second carrier signal **53***b* and the electric field **56***b* of the second side-band signal **54***b*.

For example, just at the category decision height **23**, the second airborne receiver **13** receives only the electric field **55***b* of the second carrier signal **53***b,* wherein modulation depths of the first and the second modulation signal are the same, and the second airborne receiver **13** outputs 0 DDM, indicating to be just on the course.

When the airplane **22** is positioned higher than the center of the appointed space **24** (of FIG. 3B), electric field of the second side-band signal **54***b* emitted from the other (**7***b*) of the second transmission antennae, and consequently, the first modulation signal (90 Hz, in the example) becomes dominant, giving a positive DDM value. At the upper edge of the appointed space **24**, the DDM value shows an upper allowable limit +VDDM. When the airplane **22** is positioned lower than the center of the appointed space **24**, the second modulation signal (150 Hz, in the example) becomes dominant, giving a negative DDM value. At the lower edge of the appointed space **24**, the DDM value shows a lower allowable limit −VDDM.

The limit value of the vertical DDM (±VDDM), corresponding to the vertical width **26** of the appointed space **24**, is adjusted by controlling the comparative intensity of the electric field **56***b* of the second side-band signal **54***b* by way of the second attenuator **48** of the second course generator **4**.

As to the detection of the longitudinal position **27** of the appointed space **24**, it is also performed by receiving the electric field **55***c* of the third carrier signal **53***c* and the electric field **56***c* of the third side-band signal **54***c* emitted at the same time from the third transmission antennae **8***a* and **8***b* by way of the third reception antenna **11** of the airborne system **2** having the same polarization plane with the third transmission antennae **8***a* and **8***b*.

The third carrier signal **53***c* generated by the third transmitter **43** is supplied to the third splitter/synthesizer **46** and splitted into two signals, whereof one is supplied directly to one (**8***a*) of the third transmission antennae and the other is supplied to the other (**8***b*) of the third transmission antennae through the third phase shifter **52**. On the other hand, the third side-band signal **54***c* generated by the third transmitter **43** is supplied to the third splitter/synthesizer **46** through the third attenuator **49** and splitted into two signals, whereof one is supplied to said one (**8***a*) of the third transmission antennae after inverted, that is, phase-shifted by 180°, and the other is supplied to the other (**8***b*) of the second transmission antennae through the third phase shifter **52**.

Therefore, the third carrier signal **53***c* is emitted with the same phase form both of the third transmission antennae **8***a* and **8***b* which are arranged on the horizontal plane including the category decision height **23** symmetrically to the first vertical plane at a position appropriately offset from the second vertical plane including the center line **20** of the runway **19**, and generates an electric field pattern having single peak on the first vertical plane, that is, above a threshold line **31** perpendicular to the center line **20** at the end of the runway **19**, as represented by the electric field pattern **55***c* of FIG. 3C.

On the other hand, phase of the third side-band signal **54***c* emitted from each of the third transmission antennae **8***a* and **8***b* is 180° different with each other. Therefore, an electric field pattern having two peaks, as represented by the electric field pattern **56***c* of FIG. 3C, is generated giving null field on the first vertical plane. The third phase shifter **52** is provided for so adjusting the phase of the third side-band signal **54***c* to be supplied to the other (**8***b*) of the third transmission antennae that the side-band null plane coincides with the first vertical plane.

The third airborne receiver **14** detects its course by comparing modulation depths of the first and the second modulation signal obtained from the electric field **55***c* of the third carrier signal **53***c* and the electric field **56***c* of the third side-band signal **54***c*.

For example, just above the threshold line **31**, the third airborne receiver **14** receives only the electric field **55***c* of the third carrier signal **53***c,* wherein modulation depths of the first and the second modulation signal are the same, and the third airborne receiver **14** outputs 0 DDM, indicating to be just above the threshold line **31**.

The limit value of the longitudinal DDM corresponding to the depth of the appointed space **24**, might be adjusted by controlling the comparative intensity of the electric field **56***c* of the third side-band signal **54***c* by way of the third attenuator **49** of the third course generator **5**. However, usually, the depth is not adjusted because the narrower the depth is, the more precise detection of the window passage can be performed.

When the airplane **22** passes the longitudinal position of the window frame, that is, above the threshold line **31**, a threshold passing signal **60** output from the third detector **17** of the airborne system **2** is enabled by detecting 0 DDM output of the third airborne receiver **17**. A horizontal width detection signal **58** output from the first detector **15** is enabled when output of the first airborne receiver **12** is within the horizontal limit ±HDDM, and a vertical width signal **59** output from the second detector **16** is enabled when output of the second airborne receiver **13** is within the vertical limit ±VDDM. The AND detector **18** checks whether both the horizontal width signal **58** and the vertical width signal **59** are enabled or not when the threshold passing signal **60** is enabled.

Thus, when the horizontal and the vertical width signal **58** and **59** and the threshold passing signal **60** are all enabled at the same time, the AND detector **18** outputs a window-passage detection signal **61**.

Here, it is to be noted that the above first to the third course generator **3** to **5** can be realized making use of the same technique as is applied to the Localizer or the Glide-Path transmitter, the splitter/synthesizer or the transmission antenna of an actual ILS (Instrument Landing System), and by applying the same technique, ILS airborne receivers actualy equipped in the airplane can be used as the first to the third airborne receiver **12** to **14**.

Therefore, the window-passage detection system of the embodiment can be realized with a minimum cost.

Further, the accuracy and the reliability of the ILS, which can detect the course deviation or the height deviation of cm-level, are already well proved through flight examinations and the evaluation tests.

FIG. **5** is a schematic diagram illustrating another embodiment of the invention, wherein three appointed spaces **73***a,* **73***b,* **73***c,* each corresponding to each window frame of three categories CAT-**1**, CAT-**2** and CAT-3A defined in the RNP system precision standard proposed by AWOP of ICAO, are generated along the precision approach landing course **57** of the airplane **22** by three ground systems each having the same configuration with the ground system **1** of FIG. 1A.

The window frame of the CAT-**1** is defined to have a horizontal width of ±40 m, a vertical width of ±12 m around a point at the category decision height of 60 m on the precision approach landing course **57** having an elevation angle **28** of 3° to the runway **19**. The window frame of the CAT-**2** is defined to have a horizontal width of ±21 m, a vertical width of ±4.5 m around a point at the category decision height of 30 m on the precision approach landing course **57**, and that of the CAT-3A is defined to have a horizontal width of ±15 m, a vertical width of ±1.5 m around a point at the category decision height of 15 m on the precision approach landing course **57**.

The category decision height together with its allowable limits, which is defined according to each of categories attributed to runways, indicates a minimum height until which the airplane can fall according to instrument landing. For example, category decision height **74***a* of the appointed space **73***a* according to RNP CAT-**1** indicates that the runway **19** should be recognized with pilot's eye before the airplane **22** falls at a height of 60±12 m in the precision approach landing, category decision height **74***b* of the appointed space **73***b* according to RNP CAT-**2** indicates that the runway **19** should be recognized with pilot's eye before the airplane **22** falls at a height of 30±4.5 m and category decision height **74***c* of the appointed space **73***c* according to RNP CAT-3A indicates that the runway **19** should be recognized with pilot's eye before the airplane **22** falls at a height of 15±1.5 m.

When the runway **19** cannot be recognized at the category decision height, the precision approach landing should be abandoned to be tried again.

In the embodiment of FIG. **5**, three appointed spaces **73***a,* **73***b* and **73***c* are generated each according to three categories CAT-**1**, CAT-**2** and CAT-3A making use of three window-passage detection systems. However, more than three window-passage detection systems may be provided along the precision approach landing course **57** for detecting positions of the airplane substantially continuously.

In the following paragraphs, more detailed example of the window-passage detection system according to the above embodiments will be described.

According to ANNEX 10 of ICAO standard, usable transmission frequency range other than a nominal ILS frequency of f_0 is defined to be within $f_0 \pm \Delta f_1$ and $f_0 \pm \Delta f_2$.

Therefore, the first transmitter **41** is designed to generates the first carrier signal **53***a* by amplitude-modulating (20% in this example) the first base frequency of the nominal ILS frequency of f_0 with the first and the second modulation signal of 90 Hz and 150 Hz synchronized with each other, and the first side-band signal **54***a* by balanced-modulating the first base frequency with an inverted signal of the first modulation signal of 90 Hz and the second modulation signal of 150 Hz having the same phase with that for generating the first carrier signal **53***a.*

The second transmitter **42** is designed to generates the second carrier signal **53***b* by amplitude-modulating (20%) the second base frequency $f_0 + \Delta f$, a little different from the nominal ILS frequency within the above range ($f_0 \pm \Delta f_1$ to $f_0 \pm \Delta f_1$) with the first and the second modulation signal of 90 Hz and 150 Hz synchronized with each other, and the first side-band signal **54***b* by balanced-modulating the second base frequency with the inverted signal of the first modulation signal of 90 Hz and the second modulation signal of 150 Hz having the same phase with that for generating the first carrier signal **53***b*.

And, the third transmitter **43** is designed to generates the third carrier signal **53***c* by amplitude-modulating (20%) the third base frequency $f_0 - \Delta f$, also a little different from the nominal ILS frequency within the above range ($f_0 \pm \Delta f_1$ to $f_0 \pm \Delta f_1$) with the first and the second modulation signal of 90 Hz and 150 Hz synchronized with each other, and the first side-band signal **54***c* by balanced-modulating the second base frequency with the inverted signal of the first modulation signal of 90 Hz and the second modulation signal of

150 Hz having the same phase with that for generating the first carrier signal **53***c*.

Above setting of the first to the third base frequency is intending to make good use of frequency capturing characteristic of the first to the third airborne receiver **12** to **14**, wherein frequency components scarcely different from a tuned frequency is sharply suppressed. For the purpose, oscillation frequencies of the first to the third oscillator **38** to **40** is designed to be f_0, f_0+4 kHz, and f_0−4 kHz, respectively.

Referring to FIG. **4**, each of the first to the third base frequency having a fixed level generated by each of the first to the third oscillators **38** to **40** is supplied to the splitter **63**, and split to both the carrier modulator **64** and the side-band modulator **67**.

The base frequency supplied to the carrier modulator **64** is amplitude-modulated with addition of the first and the second modulation signal, amplified through the carrier amplifier **65** and output as the carrier signal **53** to be used as respective each of the first to the third carrier signal **53***a* to **53***c*. Meanwhile, a part of the carrier signal **53** is picked out by the carrier coupler **66** to be fed back to the carrier modulator **64** as the carrier feedback signal **70**, for obtaining high stability and low distortion of the carrier signal **53**.

On the other hand, the base frequency supplied to the side-band modulator **67** is balanced-modulated with differential of the first and the second modulation signal, amplified through the side-band amplifier **68** and output as the side-band signal **54** to be used as respective each of the first to the third side-band signal **54***a* to **54***c*. Meanwhile, a part of the side-band signal **54** is picked out by the side-band coupler **69** to be fed back to the side-band modulator **67** as the side-band feedback signal **71**, for obtaining high stability and low distortion of the side-band signal **54**.

The first and the second modulation signal of 90 Hz and 150 Hz, which are synchronized, used in each of the first to third transmitter **41** to **44** are also synchronized with each other at intervals of 30 Hz making use of a synchronous signal **72**.

As previously described, each of the first to the third carrier signals **53***a* to **53***c* is emitted from each pair of the first to the third transmission antennae **6***a*, **6***b* to **8***a* **8***b*, with the same phase, and each of the first to the third side-band signals **54***a* to **54***c* is emitted from each pair of the first to the third transmission antennae **6***a*, **6***b* to **8***a* **8***b*, with the inverse phase.

The distance d_1 between two antenna elements of the at least one pair of the first transmission antennae **6***a* and **6***b* are set to be about one wavelength so as to generate a polarization plane in parallel to a horizontal direction of the appointed space **24**. In the same way, the distance d_2 between two antenna elements of the at least one pair of the second transmission antennae **7***a* and **7***b* are set to be about one wavelength so as to generate a polarization plane in parallel to a vertical direction of the appointed space **24**, and the distance d_3 between two antenna elements of the at least one pair of the third transmission antennae **8***a* and **8***b* are set to be about one wavelength so as to generate a polarization plane in parallel to a normal direction of the appointed space **24**.

The first transmission antennae **6***a* and **6***b* are arranged as follows.

First, a reference point **30** is defined at a cross point of a perpendicular (hereafter called the z-axis **34**) of a point on the precision approach landing course **57** at the category decision height **23** and the center line **20** or the extension **21** of the center line **20** (called the x-axis **32**). Then, on a line (called the y-axis **33**) including the reference point **30** and perpendicular to both the x-axis **32** and the z-axis **34**, the first transmission antennae **6***a* and **6***b* are arranged symmetrically to the z-axis **34** separated with the distance d_1.

As to the second transmission antennae **7***a* and **7***b*, a line (called z'-axis **37**) parallel to the z-axis **34** and perpendicular to the y-axis appropriately separated from the runway **20** according to circumstances of the airport, and a line (called y'-axis **36**) parallel to the y-axis **33** and crossing both the z-axis **34** and the z'-axis **37** at the category decision height **23** are defined. Then, the second transmission antennae **7***a* and **7***b* are arranged on the z'-axis **37** symmetrically to the y'-axis **36** separated with the distance d_2.

The third transmission antennae **8***a* and **8***b* are arranged on an x'-line **35** including the cross point of the y'-axis **36** and the z'-axis **37** and parallel to the x-axis **32**, symmetrically to the y'-axis **36** separated with the distance d_3.

The distances d_1, d_2 and d_3 are preferably to be sufficiently large so that mutual coupling effect of the two antenna elements may be neglected. In the above example, they are separated with each other about one wavelength.

In the airborne system **2**, each of the first to the third reception antenna **9** to **11**, arranged orthogonal with each other, receives each of spatially synthesized electric fields generated by the three pairs of the first to the third transmission antennae **6***a*, **6***b* to **8***a* **8***b* thus arranged. Each of the first to the third airborne receiver **12** to **14** outputs a signal in proportion to each DDM of the spatially synthesized electric fields. The first detector **15** enables the horizontal width detection signal **58** when output of the first airborne receiver **12** is $-\text{HDDM} \leqq \text{DDM} \leqq +\text{HDDM}$, the second detector **16** enables the vertical width detection signal **59** when output of the second airborne receiver **13** is $-\text{VDDM} \leqq \text{DDM} \leqq +\text{VDDM}$, and the third detector **17** enables the threshold passing signal **60** when output of the third airborne receiver **14** becomes zero.

The AND detector **18** outputs the window-passage detection signal **61** when the horizontal and the vertical width signal **58** and **59** and the threshold passing signal **60** are all enabled.

With the window-passage signal **61**, the pilot takes final decision whether the landing is to be accomplished or abandoned to be tried again.

As heretofore described, on the precision approach landing course making use of the DGPS, a precise window frame satisfying the RNP system precision standard proposed by AWOP of ICAO can be generated with the first to the third course generator **3** to **5** of the invention, enabling to detect passage of the appointed space instantaneously at airborne side with cm-order precision.

Furthermore, the first to the third course generator **3** to **5** and the first to the third airborne receiver **12** to **14** can be realized by applying actual ILS technique. Therefore, the window-passage detection system can be embodied with a minimum cost, according to the invention.

What is claimed is:

1. A window-passage detecting system of an airplane having at least one ground system each comprising:

a first course generator for generating a horizontal DDM (Differential Depth of Modulation) pattern for defining a horizontal width of a virtual window frame through which a precision approach landing course of an airplane is set, by emitting a first carrier signal and a first side-band signal at the same time upwards toward the virtual window frame from a pair of first transmission antennae provided under the virtual window frame and arranged horizontally and line-symmetrically to a center line of a runway to generate a polarization plane parallel to a horizontal direction of the virtual window frame, said first carrier signal being obtained by amplitude-modulating a first base signal of a first frequency with a first and second modulation signal synchronized with each other,

said first side-band signal being obtained by balanced-modulating the first base signal with the first modulation signal whereof phase is inverted and the second modulation signal,

one of said first transmission antennae being supplied with the first side-band signal and the first carrier signal, and

the other of said first transmission antennae being supplied with the first side-band signal whereof phase is inverted and the first carrier signal;

a second course generator for generating a vertical DDM pattern for defining a vertical width of the virtual window frame, by emitting a second carrier signal and a second side-band signal at the same time in the horizontal direction toward the virtual window frame from a pair of second transmission antennae provided sideways of the virtual window frame and arranged vertically and line-symmetrically to a horizontal line orthogonal to the center line and crossing with the precision approach landing course to generate a polarization plane parallel to a vertical direction of the virtual window frame,

said second carrier signal being obtained by amplitude-modulating a second base signal of a second frequency which is a little shifted from the first frequency with the first and the second modulation signal,

said second side-band signal being obtained by balanced-modulating the second base signal with the first modulation signal whereof a phase is inverted and the second modulation signal,

one of said second transmission antennae being supplied with the second side-band signal and the second carrier signal, and

the other of said second transmission antennae being supplied with the second side-band signal whereof a phase is inverted and the second carrier signal; and

a third course generator for generating a longitudinal DDM pattern for defining a longitudinal position of the virtual window frame, by emitting a third carrier signal and a third side-band signal at the same time in the horizontal direction toward the virtual window frame from a pair of third transmission antennae provided sideways of the virtual window frame and arranged horizontally and line-symmetrically to the horizontal line orthogonal to the center line and crossing with the precision approach landing course to generate a polarization plane parallel to a normal direction of the virtual window frame,

said third carrier signal being obtained by amplitude-modulating a third base signal of a third frequency which is a little shifted from both of the first and the second frequency with the first and the second modulation signal,

said third side-band signal being obtained by balanced-modulating the third base signal with the first modulation signal whereof a phase is inverted and the second modulation signal,

one of said third transmission antennae being supplied with the third side-band signal and the third carrier signal, and

the other of said third transmission antennae being supplied with the third side-band signal whereof a phase is inverted and the third carrier signal.

2. A window-frame passage detection system of an airplane as recited in claim **1**; each of the first to the third course generator comprising:

an attenuator for controlling amplitude of respective each of the first to the third side-band signal;

a splitter/synthesizer for splitting respective each of the first to the third carrier signal into two signals each to be supplied with the same phase to each of respective each pair of the first to the third transmission antennae, and splitting respective each of the first to the third side-band signal into two signals each to be supplied with a phase 180° different with each other to each of respective each pair of the first to the third transmission antennae; and

a phase shifter for controlling phases of signals to be supplied to one of respective each pair of the first to the third transmission antennae.

3. A window-frame passage detection system of an airplane as recited in claim **1**; wherein

the virtual window frame generated by each of said at least one of ground system is arranged appropriately separated from each other when said at least one is more then one;

the horizontal width of the virtual window frame is set to represent an allowable horizontal deviation of an airplane approaching according to the precision approach landing course at a point of the precision approach landing course where the virtual window frame is generated, by controlling an amplitude ratio between the first carrier signal and the first side-band signal with the attenuator of the first course generator of said corresponding each of said at least one ground system; and

the vertical width of the virtual window frame is set to represent an allowable vertical deviation of the airplane at the point, by controlling an amplitude ratio between the second carrier signal and the second side-band signal with the attenuator of the second course generator of said corresponding each of said at least one ground system.

4. A window-frame passage detection system of an airplane as recited in claim **3**; wherein

height of said point of the precision approach landing course is category decision height of one of categories defined in RNP (Required Navigation Performance) proposed by AWOP (All Weather Operating Panel) of ICAO (International Civil Aviation Organization); and

a size of the virtual window frame is the same with allowable deviations defined in the RNP corresponding to the category decision height.

5. A window-frame passage detection system of an airplane as recited in claim **1**; wherein the polarization plane generated by each pair of the first to the third transmission antennae is orthogonal to each other.

6. A window-frame passage detection system of an airplane as recited in claim **1**, whereof an airborne system provided on an airplane comprises:

a first detector for detecting passage of the airplane inside of the horizontal width of the virtual window frame, from output of a first airborne receiver having a first reception antenna of the same polarization plane with the pair of the first transmission antennae;

a second detector for detecting passage of the airplane inside of the vertical width of the virtual window frame, from output of a second airborne receiver having a second reception antenna of the same polarization plane with the pair of the second transmission antennae;

a third detector for detecting passage of the airplane traversing the longitudinal position of the virtual window frame, from output of a third airborne receiver having a third reception antenna of the same polarization plane with the pair of the third transmission antennae; and

an AND detector for detecting passage of the airplane inside of the virtual window frame, from AND logic of outputs of the first to the third detector.

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